METHOD, SYSTEM, STORAGE MEDIUM AND SOFTWARE ARRANGEMENT FOR RADIAL PRESCRIPTION OF LONG-AXIS SLICES IN MAGNETIC RESONANCE IMAGING EXAMINATIONS

5   **CROSS-REFERENCE TO RELATED APPLICATION**

The present invention claims priority from United States Provisional Patent Application No. 60/520,080, filed November 14, 2003, which is incorporated herein by reference in its entirety.

10   **FIELD OF INVENTION**

The present invention relates to magnetic resonance imaging. More particularly, the present invention relates to a method and system for obtaining magnetic resonance images at radial slices along a predefined long-axis of an imaging target.

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BACKGROUND INFORMATION

In the field of cardiac magnetic resonance imaging ("MRI"), various types of studies utilize multiple images along different "slice" planes to analyze the target of the MRI. This is particularly true with cardiac MRI techniques that can be

20   used to map cardiac regions, such as cardiac cine examinations, perfusion, delayed enhancement, magnetization tagging, etc. Images are taken of planes along both a long-axis and a short-axis of the heart. The "long axis" is a plane parallel to the longest dimension of a target anatomical structure. The "short axis" is a plane parallel to the shortest dimension of a target anatomical structure. Conventionally, in cardiac

25   imaging, it is desirable to acquire images in the long-axis plane in a uniformly angularly-spaced radial fashion to encompass the region imaged in the short-axis slices. Also, the frequency-encoding direction of the long-axis slices are taken "down the barrel" of the heart, i.e., normal to the image plane of the short-axis images.

One limitation of existing systems and methods is their inability to

30   easily prescribe slice planes for capturing multiple images along an axis. For

example, quantitative and qualitative cardiac MRI studies utilizing magnetization tagging have become important components of the cardiac MRI examination. When performing quasi-3D tagging studies, conventional procedures obtain a number of tagged images in the short-axis plane of the heart, with two orthogonal sets of tags,

5   and combine these with tagged images obtained in the long-axis plane of the heart. Conventional techniques manually prescribe the long-axis slices.

In conventional graphical slice prescription techniques, a user defines a slice-selection ("SS") direction, a phase encoding ("PE") direction and a readout (or "frequency encoding" "RO") direction are calculated based on the SS direction. RO

10 is defined by the cross-product of the SS and PE directions, because the RO direction is normal to both the SS and PE directions. For example, let s, c and t represent sagittal, coronal, and transverse directions, respectively, and $\vec{P}_0 : (P_s, P_c, P_t)$, $\vec{R}_0 :$

(R_s, R_c, R_t) and $\vec{S}_0 : (S_s, S_c, S_t)$ represent vectors in the PE, RO, and SS directions, respectively, for a first long-axis imaging slice. Using this representation,

15 and depending on the orientation of $\vec{S}_0$, the PE vector can be provided as follows:

$$\vec{P}_0\big|_t = \left[0, S_t / K_{ct}, -S_c / K_{ct}\right]$$

$$\vec{P}_0\big|_c = \left[S_c / K_{sc}, -S_s / K_{sc}, 0\right]$$

$$\vec{P}_0\big|_s = \left[-S_c / K_{sc}, S_s / K_{sc}, 0\right],$$

where $K_{ij} = \sqrt{S_i^2 + S_j^2}$ and the suffixes to $\vec{P}_0$ indicate the direction of the SS vector.

20 $\vec{R}_0$ is then calculated by computing the vector cross-product, $\vec{R}_0 = \vec{S}_0 \times \vec{P}_0$.

Conventional systems and methods are limited in their capabilities to provide a simple approach to developing quick radial prescription of long-axis imaging slices. Conventional systems require their users to manually prescribe the long-axis planes needed to develop these radial prescriptions. An examination

25 typically consists of 8-10 slices which should be uniformly angularly spaced. As a result, manual prescription of long-axis slices can be a tedious process, and prone to error.

OBJECTS AND SUMMARY OF THE INVENTION

There exists a need to provide an improved method and system for automatically prescribing long-axis magnetic resonance imaging ("MRI") MRI slices which overcomes at least some of the above-referenced deficiencies. Accordingly, at

5   least this and other needs have been addressed by exemplary embodiments of the method and system for automatically prescribing long-axis MRI slices according to the present invention. One such exemplary embodiment is directed to a method of automatically prescribing radial slice planes for magnetic resonance imaging ("MRI") along a long-axis of a target. Vectorial components can be acquired for a short-axis

10   imaging slice of the target. Vectorial components may be established for a first long-axis slice using the vectorial components of the short-axis slice. A plurality of long-axis slice planes can be defined in a manner positioned relative to the first long axis slice, rotating about a long axis in a direction of a long-axis frequency encoding vector.

15   In another exemplary embodiment of the present invention, an MRI apparatus is provided. The apparatus may include a processor that can be configured to execute instructions for performing a method of automatically prescribing radial along a long-axis of a target. The method provides vectorial components for a first long-axis slice of a target using vectorial components of a short-axis slice of the

20   target. A plurality of long-axis slice planes may then be defined relative to the first long-axis slice, rotating about a long axis in a direction of a long-axis frequency encoding vector. A frequency shift can be calculated for the long-axis slices. The apparatus may further include an RF transmitter in communication with the processor. The transmitter can generate an RF pulse toward a target in response to a signal from

25   the processor to capture an image at each of the plurality of long-axis slice planes. The apparatus may further include an RF receiver in communication with the processor, and the RF receiver can receive data from echoes created by the pulses and sends the data to the processor.

In yet another exemplary embodiment of the present invention, a

30   tangible, computer-readable medium is provided. The medium has stored thereon computer-executable instructions for performing a method of automatically

prescribing radial slice planes for magnetic resonance imaging ("MRI") along a long-axis of a target. The method can provide vectorial components for a first long-axis slice using vectorial components for each of a plurality of short-axis imaging slices of the target. The method can further define a plurality of long-axis slice planes

5   positioned relative to the first long axis slice. Each of the long-axis slices is positioned relative to a long axis, rotating about the long axis in a direction of a long-axis frequency encoding vector.

BRIEF DESCRIPTION OF DRAWINGS

10   The detailed description will refer to the following drawings, wherein like numerals refer to like elements, and wherein:

          Figure 1 shows a perspective view of a heart to be imaged, along with short-axis and long-axis planes which illustrates an exemplary interrelationship between a short-axis plane and a long-axis plane derived from the short-axis plane as

15   applied according to an exemplary embodiment of the present invention;

          Figure 2 shows a flow chart of one exemplary embodiment of a method of the present invention for automatically prescribing radial slice planes along a long-axis of a target, such as a patient's cardiac region;

          Figure 3 shows further details a flow chart of another exemplary

20   embodiment of the method of the present invention for automatically prescribing the radial slice planes along the long-axis of the target, such as the patient's cardiac region, which is shown in Figure 2;

          Figure 4 shows an exemplary embodiment of an MRI apparatus which may be used to implement the method illustrated in Figures 2 and 3; and

25   Figure 5 shows exemplary eight (8) long-axis slices of the target, such as the cardiac region of the patient, prescribed according to an exemplary method of the present invention.

DETAILED DESCRIPTION

          Figure 1 shows a perspective view of a heart to be imaged, along with

30   short-axis and long-axis planes. This figure illustrates the interrelationship between

the short-axis plane (also referred to as a "slice" or "slice plane") 250 containing a short axis 221 and a long-axis plane 201 containing a long axis 220. The long-axis plane 201 is derived from the short-axis plane 250. An image is acquired along the short-axis slice 250, and used to define the long-axis slice plane 201.

5　　　　　　　　Figure 2 shows a flow chart of one exemplary embodiment of a method 100 according to the present invention for automatically prescribing radial slice planes along a long-axis of a target, such as a patient's cardiac region. An image along the short-axis slice 250 of the target region is acquired in step 110. Vectorial components for the short-axis slice 250 are extracted in step 120 from the short-axis

10　　slice image. It should be understood the the short-axis vectorial components obtained from the image coordinates, and can be stored in memory or another storage arrangement, preferably along with associated position information which can be used to subsequently acquire other images. For example, the "image" of the short axis that is displayed, and from which is chosen the location of the axis around which the

15　　subsequent long axis images are to be rotated, can itself stored in the memory of the MRI apparatus, and has associated with it a stored set of "header information" data that specifies its orientation and location in space. This position information may be used in the calculation of the long axis image locations. Vectorial components of the long-axis slice 201 can be established in step130 using the extracted short-axis

20　　vectorial components. Additional long-axis slice planes (e.g., 202-208 shown in Figure 5) can be defined in step 140 relative to the long-axis plane 201, rotating about the long axis 220 in a direction of the long-axis frequency vector. The frequency and phase of an RF transmitter and RF receiver of an MRI apparatus can be modified in step 150 to accommodate the long-axis slice planes (e.g., 202-208 shown in Figure 5).

25　　　　　　　Figure 3 shows a detailed illustration of a flow chart of the exemplary embodiment of the method 101 for automatically prescribing radial slice planes along the long axis 220 of the target, such as a patient's cardiac region, that includes many of the steps described above with respect to Figure 2 in greater detail. as described above, the image along the short-axis slice 250 of the target region is acquired in step

30　　110. The short-axis slice 250 may include vectors $\bar{P}'$, $\bar{R}'$, and $\bar{S}'$ that represent the PE, RO and SS vectors for the short-axis image, as illustrated in the exemplary

embodiment shown in Figure 1. The short-axis slice vectors $\vec{P}'$, $\vec{R}'$, and $\vec{S}'$ are extracted in step 122 from the short-axis image.

These short-axis vectors can be used to define long-axis vectors. For example, the short-axis slice plane and frequency-encoding vectors may be transposed
5   to define long-axis frequency-encoding ($\vec{R}_0$) and slice selection ($\vec{S}_0$) vectors,

$$\vec{R}_0 = \vec{S}' \text{ and } \vec{S}_0 = \vec{R}',$$

and the long-axis phase-encoding vector ($\vec{P}_0$) is set equal to the short-axis PE vector

$\vec{P}_0 = \vec{P}'$. The orientation of the long-axis vectorial components is illustrated in the embodiment of Figure 1. It should be understood that the choice of the long-axis PE
10   vector to lie along the short-axis PE vector as cited in this exemplary figure is only one of many arbitrary choices that could be made. For another orientation of the long axis mage, it may lie in another direction within the original short-axis image, according to the intersection of the new long-axis image with the short-axis image.

Having established the vector components for the first slice 201 in the
15   long-axis direction, the next step 140 is preformed to define the multiple slice planes (e.g., 202-208 shown in Figure 5) in the long axis direction, such that the long-axis slice planes rotate about the long axis 220 in the frequency-encoding direction, and are spaced at substantially equal angles. If n planes are to be prescribed, then the vector $\vec{P}_i$ for the ith plane may be defined in step 142 as

20.
$$\vec{P}_i = \vec{P}_0 \cos\left(180 \times \frac{i}{n}\right) + \vec{S}_o \sin\left(180 \times \frac{i}{n}\right).$$

If n planes are to be prescribed, then the vector $\vec{S}_i$ for the ith plane is defined in step 144 as

$$\vec{S}_i = \vec{S}_0 \cos\left(180 \times \frac{i}{n}\right) - \vec{P}_o \sin\left(180 \times \frac{i}{n}\right).$$

The frequency-encoding vector $\vec{R}_i$ can be defined in step 146 as the frequency
25   encoding vector for the first long-axis slice, $\vec{R}_i = \vec{R}_o$. The result of application of the

exemplary method according to the present invention is a plurality of n defined long-axis planes spaced apart by equal angles about the long axis 220.

Having developed the orientation of the long-axis slices, frequency and phase modifications can be generated in step 150 e.g., to ensure identical position

5   vectors for each of the long-axis the slices. In the exemplary embodiment of the method the flow chart of which is shown in Figure 3, the frequency and phase can be modified by calculating and applying a slice-select frequency shift (fs_i), a readout frequency shift (fr_i), and a phase shift (ps_i). If $\vec{X}_o$ is the position vector of the long-axis slice 201, then the position vector for the ith long-axis slice plane may be

10   defined as the position vector of the long-axis slice 201: $\vec{X}_i = \vec{X}_o$. The frequency and phase shifts may be calculated using amplitudes of the slice-select and readout gradients G_s, G_r, respectively, and using the phase field-of-view (PFOV) and the gyromagnetic ratio γ (in MHz/T). The frequency shift for the slice-select, fs_i, direction for the ith slice is calculated in step 152 as

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$$fs_i = \gamma \cdot G_s \cdot \vec{X}_i \bullet \vec{S}_i.$$

The frequency shift for the readout, fr_i, direction for the ith slice may be calculated in step 154 as

$$fr_i = \gamma \cdot G_r \cdot \vec{X}_i \bullet \vec{R}_i.$$

The phase shift ps_i in the phase-encode direction is calculated 156 as

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$$ps_i = \frac{360.0}{PFOV} \vec{X}_i \bullet \vec{P}_i.$$

For example, a frequency shift may be applied to the transmitted RF pulse during slice-selective excitation to ensure that the location of the long-axis slice will lie at the desired location along the slice-select gradient S₀. The phase-encoding gradient P₀ may be applied after excitation but prior to signal detection; the

25   orientation of the phase-encoding gradient is chosen to be within the plane of the excited long-axis slice and perpendicular to the long axis of the heart (or other desired

object to be imaged) itself. The frequency encoding or readout gradient R_0 can be applied during the detection of the signal; it is chosen to be perpendicular to both the other gradients (and thus along the axis of the heart). Phase shits can be employed during the image acquisition or afterward, during image processing, to shift the

5   effective location of the image within the image plane, if desired.

Figure 4 shows an exemplary embodiment of an MRI apparatus 10 which may be used to implement the exemplary method 100 or 101 described above with respect to Figures 2 and 3. A radio frequency ("RF") pulse 82 is transmitted in step 110 by an RF transmitter 50 of the MRI apparatus 10 toward a target 80. In one

10   exemplary embodiment, the method 100 or 101 applies to cardiac MRI techniques and the target 80 is a patient's cardiac region. The RF pulse 80 generates an echo 84 from the target 80, which is received 120 by an RF receiver 60 of the MRI apparatus 10. In one exemplary embodiment, a single device – a transceiver – is used as both an RF receiver 60 and an RF transmitter 50.

15   For example, the received echo 84 is processed by the processor 20 of the MRI apparatus 10 using instructions 72 stored in a storage device 70 (e.g., memory). The processor 20 can extract data from the received echo 84. The data may be stored by the MRI apparatus 10, for example, in the storage device 70. The MRI apparatus 10 may be operated, for example, using the input device 30 to control

20   the processor 20. Results from the processing may be displayed or otherwise output using the output device 40 (e.g., a display).

Figure 5 shows eight (8) exemplary long-axis slices 201-208 of the target, such as the cardiac region of a patient, prescribed according to the exemplary embodiments of the methods of the present invention. The long-axis slice 201 can be

25   defined using vectors of a short-axis slice, such as the slice shown in Figure 1. The other long-axis slices 202-208 may be defined about the long axis 220, spaced at substantially equal angles from each other, as shown in Figure 5.

Although the present invention has been described with respect to particular embodiments thereof, variations are possible. The present invention may

30   be embodied in specific forms without departing from the essential spirit or attributes thereof. For example, although the present invention is illustrated in connection with

MRI techniques using magnetization tagging datasets, and using MRI of the cardiac region, one skilled in the art will recognize that the present invention is applicable to any MRI study in which it is desirable to prescribe radial long-axis slices of a target.

In addition, although aspects of an implementation consistent with the present invention are described as being stored in memory, one skilled in the art will appreciate that these aspects can also be stored on or read from other types of computer program products or computer-readable media, such as secondary storage devices, including hard disks, floppy disks, CD-ROMS, a carrier wave from the Internet or other network, or other forms of random access memory ("RAM") or read-only memory ("ROM"). It is desired that the embodiments described herein be considered in all respects illustrative and not restrictive and that reference be made to the appended claims and their equivalents for determining the scope of the present invention.